Original Research Article

Phasic development of rice during the present and future climatic conditions in central zone of Kerala

ABSTRACT

Rice is the staple food of more than half of the global population. The duration of each phenophase of rice is influenced by weather parameters. The two varieties were used in the experiment were Jaya (medium duration) and Jyothi (short duration). The two phenophase of rice has been considered in this study i.e. 50% flowering and physiological maturity. During the base period, Jyothi took 71 days to reach 50% flowering and the total duration was found to be101 days while in Jaya 75 days were taken to reach 50% flowering and 108 days for reaching physiological maturity. The phenophase has been predicted from the Infocrop and CERESDSSAT for both varieties during the base period. In case of 50% flowering, in JyothiCERES DSSAT predicted more accurately while in Jaya Infocrop predicted more accurately. The prediction of physiological maturity was found to be more accurate using CERES DSSAT in Jaya and Infocrop in Jyothi. Climate change is having a significant impact on the duration of crop. The future climate has been estimated using GFDL CM3 model and the phenophase has been predicted using Infocrop and CERES DSSAT model. In future the duration of Jyothi is expected to reduce by 3-6 days while in Jaya 5-6 days.

Keywords: Phenophase, Infocrop, CERES DSSAT, Rice, 50% flowering, Physiological maturity

1. INTRODUCTION

Rice is the primary food source for more than half of the world's population, providing 35-80 percent of the daily calorific intake requirements of Asia's 3.3 billion people (Bandumula, 2018). It is one of the world's oldest products with the largest cultivated agricultural lands in the world, serving as the primary food for millions of people all over the world (Babaee et al., 2021). Rice production is also a major source of income and employment for over 200 million people globally (Muthayya et al., 2014).

Changes and variations in prevalent meteorological factors such as precipitation, maximum and minimum temperatures, sunshine and humidity pose threats to crop performance from the beginning of the growing season to estimated outputs, resulting in food insecurity around the world (Chung et al., 2015). Rice is among the crops that are sensitive to any weather variations particularly with water, light, and heat (Shannon &Motha, 2015).

Climate change, which is marked by rising carbon dioxide levels and temperatures, as well as increased rainfall uncertainty, can have a considerable impact on crop phenology, growth, development, and yield. As a result, food security in developing countries like India may be challenged if a climatic shift has a detrimental influence on crop growth and production. As a result, it's critical to estimate the potential influence of climate change on rice harvests (Aggarwal and Mall, 2002).

It is critical to understand how climate change will influence rice crop growth, development, water usage, and productivity in India. There are two techniques in tackling the problem. First, in glasshouses, or open-top chamber, assess the direct impacts of changing weather conditions and CO_2 concentration on crop growth; second, model plant growth, development, and yield. The first approach takes a long time and is extremely expensive.Crop simulations give us the ability to generate agricultural production scenarios in changing climates (Saseendran et al., 2000).

The Indian Institute of Agricultural Research created the generic InfoCrop-Rice model. Phenological development of rice is divided into three main stages: sowing to emergence, emergence to anthesis, and storage organ filling. The emergence to anthesis phase is further divided into three sub-phases: basic juvenile, photoperiod sensitive, and storage organ development based on the This model was created to simulate how soil, weather, pests, agronomic practices (such as planting, residues, irrigation, and nitrogen) and planting conditions affect crop yield and the environmental problems that go along with it. Being a user-friendly model, its goal is to enhance the usage of crop models in research and development while requiring less input (Aggarwal et al., 2006).

Multiple crop models, including CERES-Rice, are included in the International Benchmark Systems Network for Agrotechnology Transfer (IBSNAT) Decision Support System for Agrotechnology Transfer (DSSAT) (Goswami and Dutta, 2020). The CERES-Rice model simulates crop growth, development, and yield, accounting for weather, genetics, soil water, carbon, and nitrogen, as well as planting, irrigation, and nitrogen fertilizer management (Ritchie et al., 1998). It has been extensively used to simulate the effects of management strategies, plant genetics, soil conditions, and weather on the development, growth, and yield of rice crop (Mall and Aggarwal 2002).

Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCCfor its fifth Assessment Report (AR5). It supersedes Special Report on Emissions Scenarios (SRES) projections published in 2000. The pathways are used for climate modeling and research. They describe four possible climate futures, all of which are considered possible depending on how much greenhouse gases are emitted in the years to come. The four RCPs are RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values.

2. METHODOLOGY

An experiment for "Comparison of Info-Crop and CERES-DSSAT models of rice under projected climatic conditions of Kerala" was done during 2021-2022 at the Department of Agricultural Meteorology, College of Agriculture, KAU, Vellanikkara.

2.1 Location of the experiment

The field work was carried out during Kharif season of 2021 at Agricultural Research Station, Kerala Agricultural University, Mannuthy, Thrissur. The station is located at 22.0 m above mean sea level (MSL) at 100 32' N latitude and 760 20' E longitude. The area experiences a typical warm humid tropical climate. The area is benefited by both southwest and northeast monsoons.

At the study field, the soil texture was sandy loam. Table.1 demonstrates the mechanical characteristics of the soil in the field.

Table 1. Physical properties of soil at the experimental field

S.No.	Particulars	Value
1	Coarse sand (%)	27.6
2	Fine sand (%)	24.2
3	Silt (%)	22.2
4	Clay (%)	26.0

2.2Varieties chosen for the study

Jyothi and Jaya, popular varieties of rice, used in the experiment. Jyothi is a short duration and Jaya is a medium duration variety with growing period of 115-120 days and 120-125 days respectively. Jyothi has been developed from the cross between PTB-10 and IR 8. As this is having wider adaptability, it is cultivated in all three seasons and in a wide range of field conditions. Jaya variety, is developed from crossing Taichung (Native) 1 and T-141, recommended for cultivation in both kharif andrabi seasons.

2.3Weather data for present conditions

The Principle AgrometObservatory of the College of Agriculture, KAU, Vellanikkara supplied the necessary weather information for the experiment, including the maximum temperature, minimum temperature, bright sunshine hours and rainfall. The bright sunshine hours converted to solar radiation using Decision Support System for Agrotechnology Transfer (DSSAT) weatherman.

2.4Weather data for future conditions

Among the four scenarios of Representative Concentration Pathways (RCPs), two are chosen for this study *viz.,* RCP 4.5 and 8.5. The first one represents a future with relatively ambitious emission reduction with stabilized radiative forcing achieved shortly after 2100. The RCP 8.5 scenario represents a future with no policy changes to reduce emissions and it can be comparable with SRES scenario of AIFI.

The Climate Change Agriculture and Food Security (CCAFS) Institute under the CGIAR system has hosted a website for providing the downscaled projection data on point basis (http://gismap.ciat.cgiar.org/MarkSimGCM/), through MarkSim^{TM} DSSAT weather file generator. This converts the downscaled weather data from global climate models (GCMs) to DSSAT weather input file format. GFDL-CM3 was used to project or represent changes in average monthly rainfall, minimum and maximum monthly temperature data for three time slices *viz.,* 2030 (near century), 2050 (mid century) and 2080 (end century).

2.5Crop simulation models

The challenges posed by climate change demand an exceptional capability to predict crop responses to environment and management. Crop growth is an extremely complex phenomena that results from a series of complex interactions between soil, plant, and weather. Dynamic crop growth simulation is a modern technique that allows for a quantitative understanding of the impact of these and other agronomic management parameters on crop growth and productivity. InfoCrop (Information on Crop) and Decision Support System for Agrotechnology Transfer (DSSAT) are such dynamic crop simulation models which are used in the current study.

2.5.1 Calibration of models

Calibration is the process of making arbitrary changes to parameter/ coefficient values in a model to match data from the real experiment. This was done by adjusting genetic coefficients. Calibration of genetic coefficients for InfoCrop and CERES-Rice model has been done with datasets including date of planting, spacing, plant density, irrigation details, leaf area, phenophases, method of harvesting and yield details.

2.5.2 Validation of models

Statistical parameters like Root Mean Square Error (RMSE), Mean Absolute Error (MAE), Mean Bias Error (MBE), and Percent Error (PE) are used to evaluate the goodness of fit and performance of the model (AgriMetSoft, 2019).

Percent Error (PE) is calculated by using the formula: (simulated-observed)/observed*100.

Root Mean Square Error (RMSE) is the square root of the variance of the residuals. It indicates the absolute fit of the model to the data–how close the observed data points are to the model's predicted values. RMSE is a standard way to measure the error of a model in predicting quantitative data.

Formally, RMSE is defined as follows:

$$RMSE = \sqrt{[\ \Sigma(Pi - Oi)^2 / n\ ]}$$

Where, Pi is the predicted value for the i^{th} observation
Oi is the observed value for the i^{th} observation
n is the sample size

RMSE is always non-negative, and a value of 0 (almost never achieved in practice) would indicate a perfect fit to the data. In general, a lower RMSE is better than a higher one.

Mean Absolute Error is simply, as the name suggests, the mean of the absolute errors. The absolute error is the absolute value of the difference between the forecasted valueand the actual value. It measures accuracy for continuous variables and indicates how big of an error we can expect from the forecast on average.

$$MAE = \frac{1}{n} \times \sum_{i=1}^{n} (|O_i - P_i|)$$

|Oi - Pi| = the absolute errors and Σ = summation symbol

Mean bias error is primarily used to estimate the average bias in the model and to decide if any steps need to be taken to correct the model bias.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(P_i - O_i)$$

3. RESULTS AND DISCUSSION

3.1 Observed phasic development of rice varieties under present climatic conditions

Duration of each phenophase for both the selected varieties had been observed and recorded from transplanting to physiological maturity. Jyothi (short duration variety) has taken 71 days and Jaya (medium duration variety) has taken 75 days to reach 50% flowering stage. During present condition, the total crop duration was found to be 101 and 108 days for Jyothi and Jaya varieties respectively.

3.2 Comparison of observed and predicted phenophase duration of crop by InfoCrop rice and CERES-DSSAT rice models for present conditions

InfoCrop and CERES models are calibrated for the duration of 50% flowering and physiological maturity stages of Jyothi (short duration variety) and Jaya (medium duration variety). Table 2 and Table 3 represents the genetic coefficients used for InfoCrop and CERES-DSSAT models respectively.

For 50% flowering phenophase, it was observed that Jyothi has taken 71 days while Jaya has taken 75 days from transplanting. Jyothi and Jaya varieties simulated by using thegiven genetic coefficients.The InfoCrop and CERES-DSSAT model predicted duration of 50% flowering stage of Jyothi variety was 73 and 71 days respectively. For Jaya variety, both models predicted the duration of 76 days to reach flowering stage. The validation for the 50% flowering prediction of both models was done. InfoCrop model showed Percent Error 28% and MAE, RMSE and MBE of 2 for Jyothi variety. CERES-DSSAT model showed 0.4 MAE, 0.6 RMSE, 0 MBE and 0% Percent Error for short duration variety viz., Jyothi. The InfoCrop and CERES-DSSAT models had 0.4 MBE and 0.5% Percent Error for the predicted duration of 50% flowering in Jaya. MAE and RMSE of 0.4 and 0.6 for InfoCrop and MAE and RMSE of 1.2 and 1.4 in case of CERES-DSSAT model was observed in Jaya variety.These validation results revealed that both crop models are good in agreement with the observed values of 50% flowering duration of rice varieties in central zone of Kerala.

The observed crop duration from transplanting to physiological maturity was 101 and 110 days in Jyothi and Jaya respectively. The InfoCrop and CERES-DSSAT models predicted crop duration was 100 and 98 days for Jyothi while it was 103 and 109 days for Jaya variety respectively. The validation for physiological maturity stage of both the varieties was carried out for InfoCrop and CERES-DSSAT models. For Jyothi variety, InfoCrop model showed 2.4 MAE, -1.6 MBE, 2.6 RMSE and -1.6 % PE. For Jaya variety crop duration, CERES-DSSAT model had MAE of 2.8, MBE of -2.8, RMSE of 3.4 and -2.7% PE. Validation of InfoCrop rice model with 7.2 MAE, -7.2 MBE, 7.4 RMSE and -6.5% PE whereas CERES-DSSAT model with 1.8 MAE, -1 MBE, 1.8 RMSE and -0.9% PE was found for Jaya variety duration. The validation results for physiological maturity duration of short and medium duration rice varieties showed that the InfoCrop as well as CERES-DSSAT models are predicting the crop duration accurately.

3.3. Predicted phenophase duration of rice under future climatic conditions

The duration of 50% flowering and physiological maturity stages of Jyothi as well as Jaya varieties were predicted using InfoCrop and CERES-DSSAT models for near century (2030), mid century (2050) and end century (2080) using two scenarios viz., RCP 4.5 and RCP 8.5 of GFDL-CM3 climate model.

3.3.1. Under RCP 4.5 scenario

3.3.1.1. Transplanting to 50% flowering stage duration

InfoCrop model predicted 70, 70, and 69 days duration in Jyothi variety in near, mid and end century respectively. For Jaya variety, InfoCrop model predicted a duration of 74, 73 and 73 days for near (2030), mid (2050) and end (2080) century respectively. CERES-DSSAT model predicted 70, 69 and 68 days for Jyothi variety and 74, 74 and 73 days for Jaya variety in near, mid and end century respectively.

3.3.1.2. Transplanting to physiological maturity duration

For Jyothi variety, InfoCrop model predicted the crop duration of 97, 96 and 94 days in near, mid and end century respectively. For Jaya variety, InfoCrop model predicted a duration of 104, 101 and 102 days was found in near, mid and end century respectively. In CERES-DSSAT model, the predicted duration for Jyothi variety was 97, 96 and 95 days and for Jaya variety was 107, 106 and 105 days in near (2030), mid (2050) and end (2080) century respectively.

3.3.2. Under RCP 8.5 scenario

3.3.2.1. Transplanting to 50% flowering stage duration

For Jyothi variety, InfoCrop model predicted 72, 70 and 69 days duration in near, mid and end century respectively. Jaya variety had shown a duration of 75, 73 and 73 days by InfoCrop model in near, mid and end century respectively. CERES-DSSAT model predicted 70, 68 and 68 days for Jyothi variety and 75, 74 and 73 days for Jaya variety in near, mid and end century respectively.

3.3.2.2. Transplanting to physiological maturity duration

For Jyothi variety, InfoCrop model predicted the crop duration of 98, 96 and 94 days in near, mid and end century respectively. For Jaya variety, InfoCrop model predicted a duration of 106, 101 and 102 days was found in near, mid and end century respectively. In CERES-DSSAT model, the predicted duration for Jyothi variety was 98, 96 and 94 days and for Jaya variety was 108, 106 and 104 days in near (2030), mid (2050) and end (2080) century respectively.

3.3.3. Comparison of phasic development of rice under present and future climatic conditions

3.3.3.1. Transplanting to 50% flowering stage duration

InfoCrop and CERES-DSSAT models showed lesser duration of transplanting to 50% flowering of rice varieties under future conditions of both the scenarios compared to present conditon, as shown in Table 2. The predicted duration of Jyothi variety was 73 days in InfoCrop model and 71 days in CERES-DSSAT model, for the base period. Under RCP 4.5 scenario, Jyothivariety duration was projected to reduce by 3-4 days whereas under RCP 8.5 scenario it's duration reduced by 4-6 days by 2080s. For Jaya variety, InfoCrop and CERES-DSSAT models predicted duration for the base period was 76 days to attain 50% flowering stage. Duration of Jaya variety is projected to reduce by 3days by the end century under both the scenarios, predicted by both the InfoCrop and CERES-DSSAT models.

Table 2.The change in duration of rice varieties from the base period to future projected climate

Scenario	Year	InfoCrop		CERES-DSSAT	
		Jyothi	Jaya	Jyothi	Jaya
Base period	2021	73	76	71	76
RCP 4.5	2030	70	74	70	74
	2050	70	73	69	74
	2080	69	73	68	73
RCP 8.5	2030	72	75	70	75
	2050	70	73	68	74
	2080	69	73	68	73

2.1.1. Physiological maturity stage

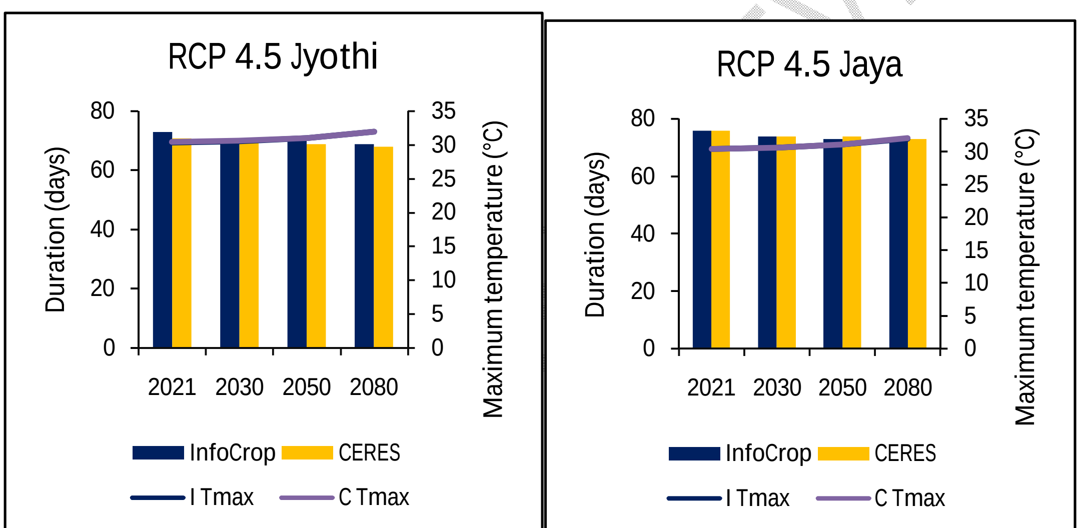
The predicted crop duration of rice varieties by InfoCrop and CERES-DSSAT models was decreased from the present to future conditions of both RCP 4.5 and 8.5 scenarios compared to base period for both Jyothi (short duration variety) and Jaya (medium duration variety), as shown in Table 3. Jyothi variety shown crop duration of 100 days in InfoCrop model and 98 days in CERES-DSSAT model, for the base period. Under RCP 4.5 scenario, Jyothi variety showed reduction of 3-6 days whereas under RCP 8.5 scenario it's duration reduced by 2-4 days by 2080s. For the base period, Jaya variety had predicted crop duration of 103 and 109 days by InfoCrop and CERES models respectively. The crop duration of Jaya variety was projected to reduce by 1-4 days under RCP 4.5 scenario and 1-5 days under RCP 8.5 scenario by the end (2080) century.

Table 2.The change in duration of rice varieties from the base period to future projected climate

Scenario	Year	InfoCrop		CERES-DSSAT	
		Jyothi	Jaya	Jyothi	Jaya
Base period	2021	100	103	98	109
RCP 4.5	2030	97	104	97	107
	2050	96	101	96	106

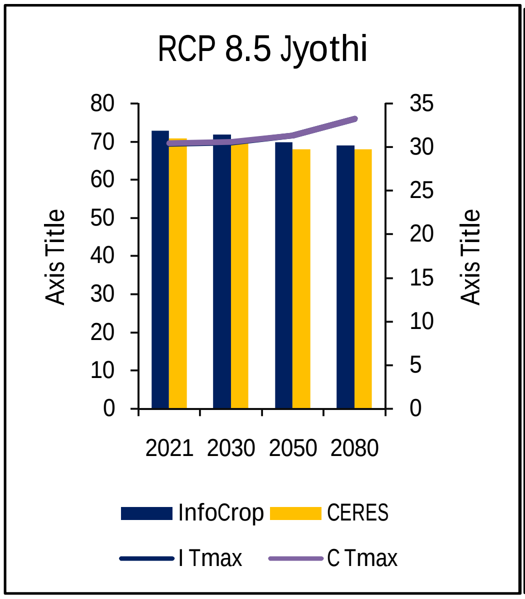
	2080	94	102	95	105
RCP 8.5	2030	98	106	98	108
	2050	96	101	96	106
	2080	94	102	94	104

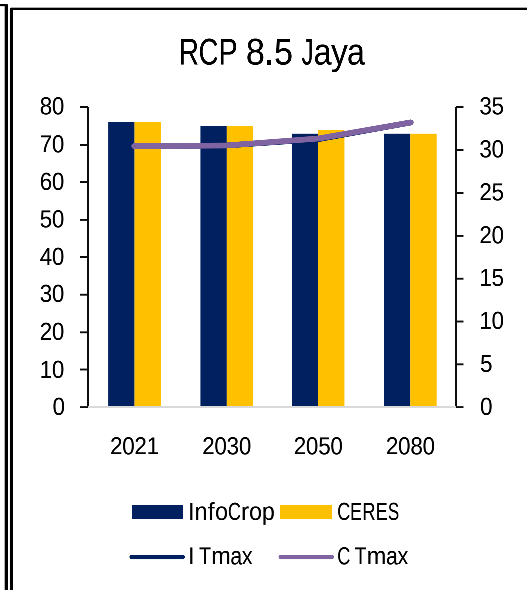
Impact of maximum temperature on duration of transplanting to 50% flowering stage of Jyothi and Jaya under RCP 4.5 is shown in Figure 1 (a) and (b) respectively. The duration of 50 % flowering stage under RCP 8.5 scenario is represented in Figure 2 (a) and (b) for Jyothi and Jaya varieties respectively. Raoufi and Soufizadeh (2020) simulated the impacts of climate change on phenology, growth and yield of various rice genotypes in humid sub-tropical environments using AquaCrop-Rice model. The results showed that the temperature was more influencing both the vegetative and reproductive phases. They reported that the higher temperature accelerates the flowering as well as physiological maturity stage.



(a) (b)

Fig. 1. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the transplanting to 50% flowering duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety

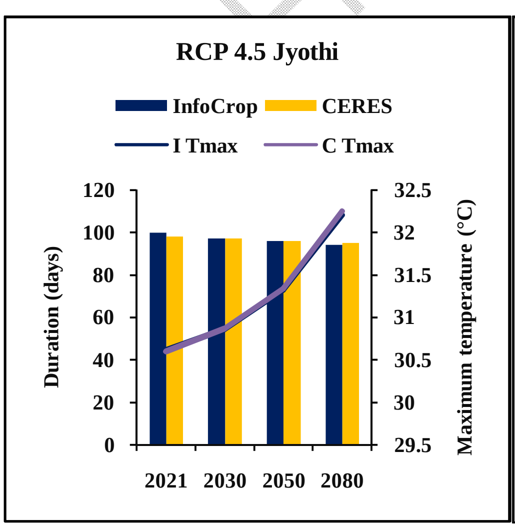


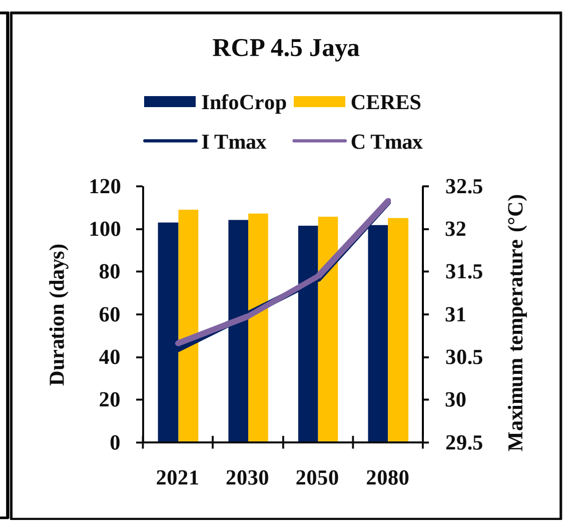


(b) (b)

Fig. 1. Impact of maximum temperature during present and future conditions under RCP 8.5 scenario on the transplanting to 50% flowering duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety

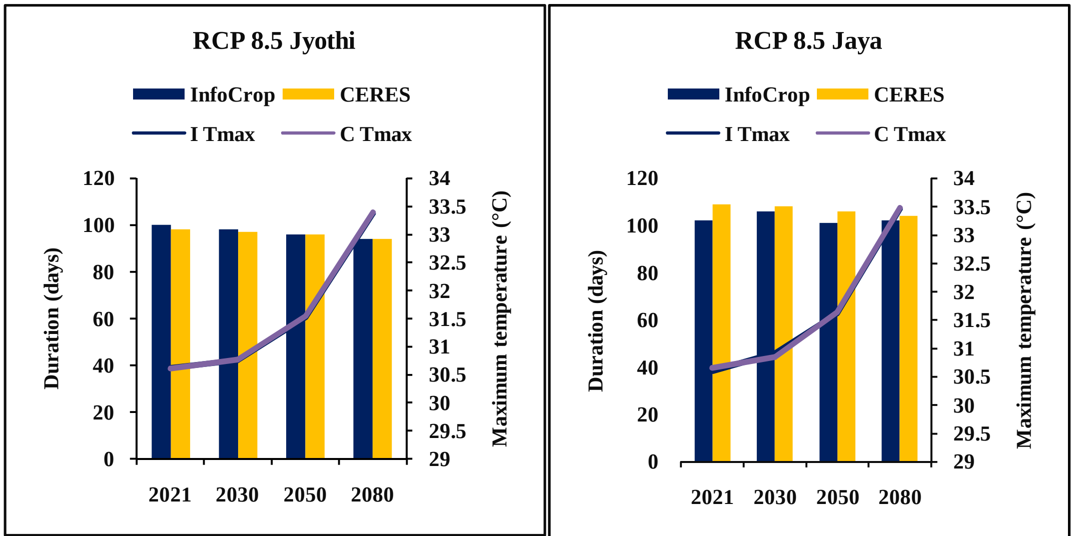
For the base period, there was lowest temperature compared to future projections and this might caused the crop to attain maturity stage earlier than present conditions. Zhang and Tao (2013) modeled the response of rice phenology to climate change and variability in different climatic zones. They found that under future climate scenarios, all the five models considered for the study, predicted the reduction in the duration of rice crop with temperature rise. Saseendran et al. (2000) studied the effect of climate change on the rice crop in humid tropical humid conditions of Kerala, using CERES rice model, in which they found that the rice maturity period is projected to shorten by 8% with temperature rise in future.





(c) (b)

Fig. 3. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety



(a) (b)

Fig. 4. Impact of maximum temperature during present and future conditions under RCP 4.5 scenario on the duration of (a) Jyothi - Short duration variety (b) Jaya - Medium duration variety

Conclusion:

From the study, it was found that the temperature rise in future have significant impact on the duration of both 50% flowering and physiological maturity in rice varieties. The InfoCrop and CERES-DSSAT models are predicting the reduced duration from the present situation to future simulations. Both short duration as well as medium duration varieties may experience higher maximum temperature and this might have reduced the crop duration in future compared to base period.

COMPETING INTERESTS

Declaration of competing interest should be placed here. All authors must disclose any financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work. Examples of potential conflicts of interest include employment, consultancies, honoraria, paid expert testimony, patent applications/registrations, and grants or other funding. If no such declaration has been made by the authors, SDI reserves to assume and write this sentence: “Authors have declared that no competing interests exist.”.

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Authors may use a form from their own institution or SDI Patient Consent Form 1.0. It is preferable that authors should send this form along with the submission. But if already not sent during submission, we may request to see a copy at any stages of pre and post publication.

If the person described in the case report has died, then consent for publication must be collected from their next of kin. If the individual described in the case report is a minor, or unable to provide consent, then consent must be sought from their parents or legal guardians.

Authors may use the following wordings for this section: "All authors declare that ‘written informed consent was obtained from the patient (or other approved parties) for publication of this case report and accompanying images. A copy of the written consent is available for review by the Editorial office/Chief Editor/Editorial Board members of this journal."

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DEFINITIONS, ACRONYMS, ABBREVIATIONS

Here is the Definitions section. This is an optional section.
Term: Definition for the term

APPENDIX